

Modeling Varistors with PSpice: Simulation Beats Trial and Error

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Programs for simulation of electronic circuits have been used for some time. The best known is the Spice simulator developed in the mid-1970s, now available worldwide in many variants. Spice software uses mathematical models for a wide range of components. It calculates and tests the desired circuit function from simulation data compiled by the designer, then outputs the results in an easy-to-interpret form. Resulting benefits, such as high operational reliability and fewer test circuits, cut development time and costs. Working in a Microsoft Windows environment, designers can generate a simulated circuit in the usual way, by inputting a circuit diagram of components from one of the extensive libraries now available.

The PSpice Simulator from OrCAD Inc. (Beaverton, OR, USA) is one of the most popular program packages for circuit simulation. The varistor model for PSpice is described by four parameters, which designers can access in the model library with the PSpice model editor.

To create a model with PSpice, the varistor is replaced by a current-voltage characteristic, a parallel capacitance, and a series inductance (Figure 1). The current-voltage characteristic is simulated by a controlled voltage source V , which is a function of current I . An additional series resistance R_2 of 100 $\mu\Omega$, which is not visible in the basic configuration, is inserted into the model. The current-voltage characteristic

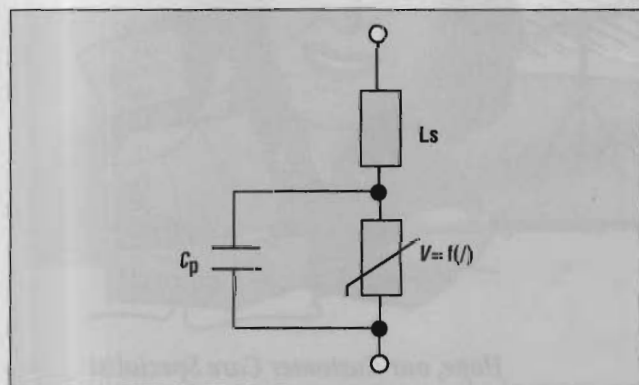


Figure 1. Basic structure of varistor model for simulation with PSpice.

prevents invalid conditions from arising as a result of connection of ideal sources in parallel or direct connection of the varistor model to a source. This can be described mathematically by the following approximation:

$$\log V = b1 + b2 \times \log(I) + b3 \times e^{-\log(I)} + b4 \times \log(I) \text{ when } I > 0$$

The characteristic for a particular varistor can therefore be described by parameters $b1$ to $b4$. The typical V/I characteristic for the varistor we used for modeling and its associated parameters are shown in Figure 2. The characteristic

Spice software uses mathematical models for a wide range of components, calculating and testing desired circuit function.

can move within its tolerance range defined by the specified varistor voltage. The standard tolerance for varistors is 10%. The tolerance range can be simulated with the parameter TOL by shifting the mean varistor characteristic. The typical characteristic (middle curve) is obtained when TOL is zero. The upper curve relates to a varistor voltage tolerance of +10% (TOL=10) and corresponds to the curve shown in the manufacturer's data book for the maximum protection level. The lower curve relates to a tolerance of -10% (TOL=-10) and corresponds to the curve shown in the data book for maximum leakage current at currents up to 1 mA.

The typical capacitance given in the manufacturer's data book is inserted into the model. We ignored the slight variation of capacitance with the voltage applied and frequency for this study. The inductance of the varistor, on the other hand, must not be ignored in applications with steep pulse edges. It is therefore covered by a series inductance and largely determined by the inductance in the leads attached to the ceramic disk. On the other hand, the internal inductance of the zinc oxide varistor can be ignored. The inductance

resonant frequencies (in the low hundreds of megahertz). This discovery raises questions as to the validity of existing standards. The WG2 has initiated testing to assess the magnitude of this effect. Underwriters Laboratories has been performing the tests based on a protocol developed by the working group.

Conclusion

Clearly, this has been a very active year for developments in EMC and medical electronics. As existing standards are revised, we expect that the U.S. and European Union standards will be brought into closer alignment in the near future.

At the same time, we see that as new technologies are introduced and become widespread, interference is likewise evolving. Continuous vigilance will still be needed to keep on top of these issues. In particular, we see that nonmedical electronics are becoming an increasing factor for medical devices (see sidebar). We expect that the manufacturers of these nonmedical products are going to become increasingly involved in medical EMC, like it or not.

Acknowledgments

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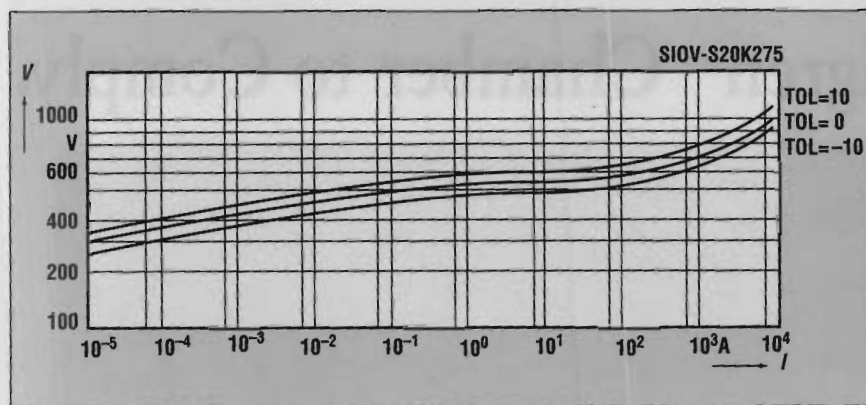


Figure 2. V/I characteristic of the varistor studied, with $\pm 10\%$ tolerance band.

values covered in the model library apply to typical varistor mountings. An inductance of about 13 nH is obtained for the varistor studied. Longer varistor leads can be modeled by inserting additional inductances into the simulation circuit. The specific inductance of the leads of disk varistors is about 1 nH per millimeter.

The Limits of Modeling

For mathematical reasons, the V/I characteristic is extended in both directions beyond the current range ($10 \mu\Omega$ to $I_{\max}$) specified in the data book and is not limited by PSpice. If the simulation exceeds these limits, the model loses validity. Values of less than $10 \mu\Omega$ can therefore lead to incorrect simulation results, but do not endanger the real component. Moreover, exact knowledge of leakage currents in the range of up to $10 \mu\Omega$ is only required in exceptional cases for varistor applications. But confidence in values above the type-specific surge current $I_{\max}$ can lead to destruction of the real component as well as falsification of the result. What's more, the varistor model does not check compliance with other limit values, such as maxi-

mum continuous power or pulse derating. Therefore this compliance must always be verified against the figures in the data book as well as by simulation.

Zinc oxide varistors have a negative temperature coefficient of voltage. This coefficient, TK, is equal to 0.05% K and decreases as current density increases. However, this relationship is not reproduced in the model because it has negligible influence on the protection level of the varistor.

Pulse Test Simulation

A test pulse of 10/700 μs duration as specified by CCITT or IEC 1000-4-5 is often used to check interference immunity of telecommunications equipment. The test pulse is defined by the test generator circuit and the given open-circuit voltage. For an open-circuit voltage of 2 kV, the charging capacitor must be charged up to 2.05 kV. An additional resistance R1 of 10 M Ω is inserted at the output to prevent undefined floating of Rm2.

For worst-case simulation, i.e., the maximum protection level, the tolerance of the upper characteristic (TOL = 10) is used for the varistor. There is no need to simulate the equipment to be protected because it can be regarded as high impedance with respect to the varistor when the test pulse is applied. The curves calculated (Figure 3) show that the varistor can reduce the interference voltage at the equipment connected to 2 kV to less than 260 V. For a maximum current $I_{\max}$ of 44 A and integral idt of 17 mAs, the time t_r required for an equivalent area rectangle is 386 μs ($17 \text{ mAs} \div 44 \text{ A}$). The derating field for the varistor studied (Figure 4) shows that with this value and at the maximum current $I_{\max}$, ten pulse loads can be applied.

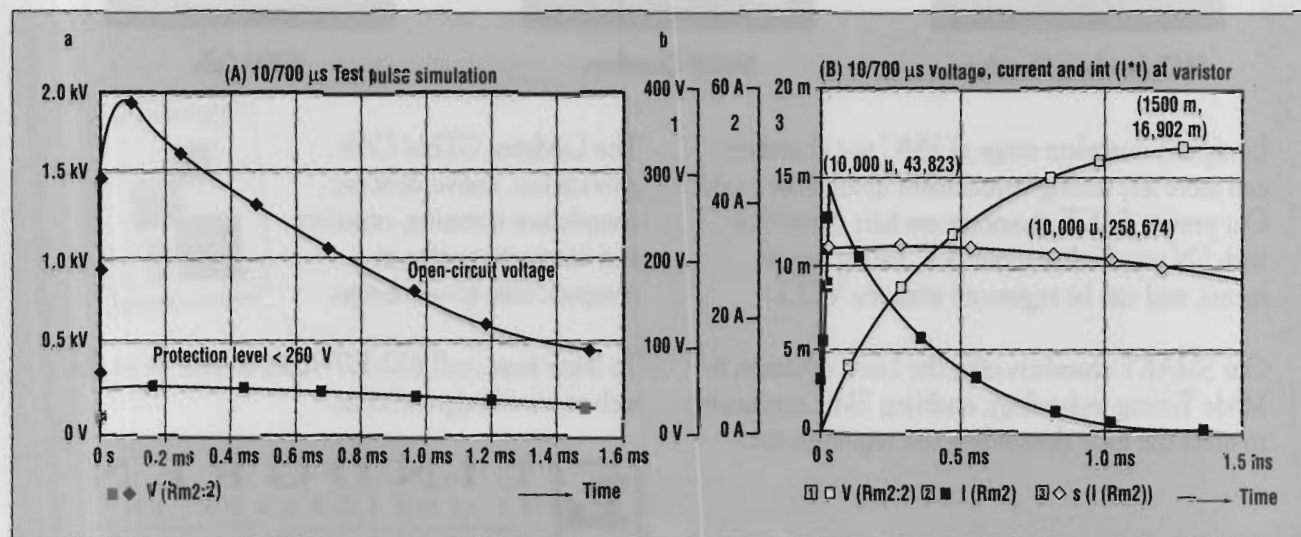


Figure 3. Simulation results: a) Test pulse simulation. b) Curve of voltage at varistor, current through varistor and current-time integral idt .

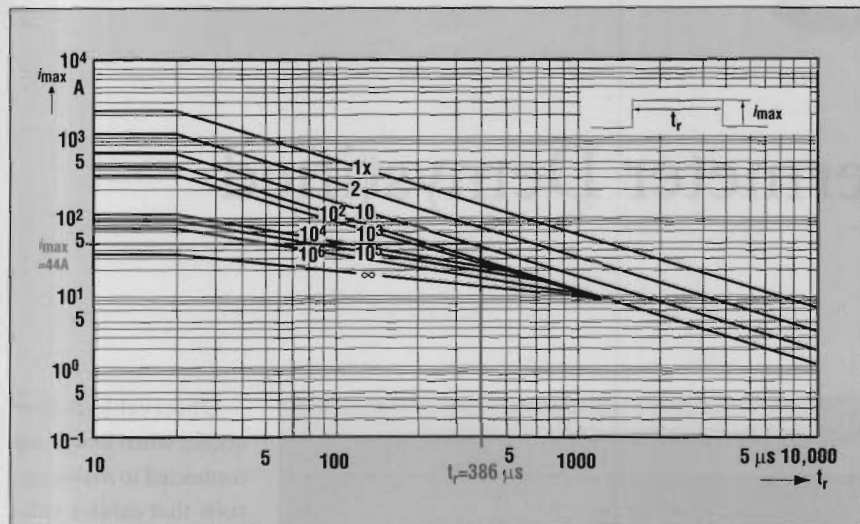


Figure 4. Ten pulse loads can be applied at maximum current to the varistor studied.

PSpice can also determine the energy absorbed by the varistor with the formula $W = v i_{dt}$, in this case 4.2 J. In conjunction with the varistor's maximum continuous power-handling capacity, P_{max} , of 0.4 W, the minimum pulse interval, T_{min} , can be determined as follows: $T_{min} = W/P_{max} = 4.2 \text{ J}/0.4 \text{ W} = 10.5 \text{ s}$.

Since ten pulses with a duration of 10/700 μs applied at one-

minute intervals are specified for telecommunications equipment, the varistor studied is suitable for this application.

Whether the varistor's operating voltage of 95 V_{rms} is suitable for the application depends on the protection level required for the equipment as well as the operating voltage (e.g., dc supply voltage, ringing tone voltage). If required, lower protection levels can be obtained by using a lower operating voltage or a larger-diameter varistor. However, designers should always make sure that the maximum operating voltage is equal to or less than the maximum operating voltage of the varistor.

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The UIE Flickermeter Demystified

JAMES MCKIM

As product regulations engineers, test houses, and manufacturers prepare for the eventual application of EN 61000-3-3 to a broad range of products, there is a growing desire to understand the phenomenon of flicker and the operation of the instrument

used to measure it, the UIE flickermeter. Despite the seemingly strange names, flicker is actually a fairly common phenomenon and the measuring instrument little more than an adaptation of a familiar frequency domain signal analyzer.

The Flicker Phenomenon

Most people have experienced the sensation of varying light intensity from incandescent lamps as other loads connected to the same mains circuit draw varying currents. This perceptible variation in luminous intensity is flicker. In domestic environments, hot plates, air conditioners, and laser printers are common examples of equipment that can generate observable flicker. A more precise description of flicker found in EN 61000-3-3 defines it as "... the subjective severity of the flicker imposed on the light from 230-V, 60-W coiled-coil filament lamps by fluctuations of the supply voltage."

Specifications in EN 61000-3-3 and in related IEC standards defining measuring instrumentation apply exclusively to 50-Hz systems, but work is under way to provide additional specifications suitable for use in 60-Hz systems. Flicker is defined in terms of incandescent lamp behavior because of common usage and because incandescent lamps exhibit greater sensitivity to voltage changes. Flicker may also be observed with fluorescent lamps.

The engineering unit for instantaneous flicker sensation is defined in such a way that a value of 1 corresponds to the perceptibility threshold for 50% of the human population. Flicker is fundamentally a physiological phenomenon and is modeled to account for the overall response characteristics of the lamp-eye-brain system.



An ac test source is embedded with the UIE flickermeter.

Observable flicker occurs when lamps are connected to mains circuits that exhibit voltage fluctuations. Voltage fluctuations usually result from varying current drains of other connected equipment. The mains system is most commonly viewed

as an ideal voltage source,

but in fact, all mains systems exhibit significant source impedance, particularly at the low-voltage (LV) level. IEC 725 (1981) defines a standard, or reference, value of $0.4 + j0.25 \Omega$ for the low-voltage system impedance in single-phase European mains networks. The selected value corresponds to the 90th-percentile system impedance level measured in European LV systems. For three-phase systems, the impedance is allocated between the phase and neutral conductors, but sums to the same total value.

Figure 1 shows a simplified circuit diagram for a system in which time-varying currents flowing through the mains' system impedance cause varying mains voltage inputs to a lamp connected to the same circuit as the load drawing the varying currents. In this case the flicker source is shown connected to the same low-voltage branch circuit, but observable flicker may be generated by sources elsewhere in the system. Large industrial loads such as welders and arc furnaces connected at the

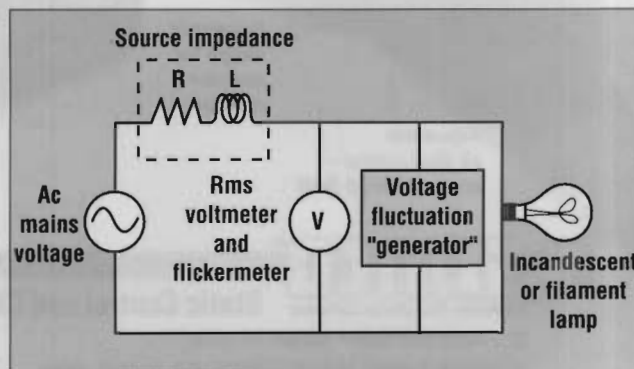


Figure 1. Simplified circuit diagram.